A two-year study of parental obesity status and childhood obesity in China

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Abstract *Background and aims:* We evaluated the association between parental obesity and their children's obesity parameters [e.g., percentage of body fat (PBF)] over time.
Methods and results: The study included 2066 Chinese parents-children trios (n = 1001 girls and 1065 boys, aged 6–14 years). Children's height, weight, waist circumference (WC) and PBF (bioelectrical impedance analysis) were annually assessed from 2014 (baseline) to 2016. Information on parental height and body weight, and children's diet and physical activity was collected in 2014. The association between parental obesity and changes in their children's PBF during follow-up was analyzed using a mixed effects model. We also examined changes in children's BMI and WC in secondary analyses. Baseline mean BMI, WC, and PBF for children were 17.6 ± 3.5 kg/m^2, 60.5 ± 9.6 cm, and $16.6 \pm 6.5\%$, respectively. We observed that maternal, but not paternal, obesity was associated with a greater increase in children's PBF during the follow-up. An adjusted mean difference in annual increase of PBF was 0.41% [95% confidence interval (CI): 0.01%, 0.84%] for children with obese mothers, compared with those with normal-weight mothers. Both maternal and paternal obesity was associated with a greater increase in their children's BMI and WC (p trend<0.01 for both); however, the associations were stronger in mother–children pairs than those in father–children pairs.
Conclusions: Maternal obesity was associated with a greater increase in PBF in Chinese school-aged children.
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Introduction

The notion of "familial aggregation of obesity" suggests that parents contribute to childhood obesity, which could be due to shared genetic and environmental factors between parents and their children [1]. Previous studies suggested that children with obese parents might have a high body mass index (BMI) in the future [2,3]; however, whether mothers and fathers have a different influence on children's BMI remains unclear. Some [4,5], but not all studies [6–8], reported that mothers could have a greater impact on children's BMI than fathers. The association between parental waist circumference (WC) and their

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children's corresponding measurement showed a similar pattern to the one identified for BMI [9,10]. However, most of the aforementioned studies are limited by their cross-sectional study design. Further, most previous studies on this topic only examined children's BMI and WC.

Body fat is an independent and alternative predictor for obesity-related metabolic diseases in children [11]. Percentage of body fat (PBF) reflects excess body fat; BMI reflects overall obesity; and WC reflects abdominal adiposity. These indices have different advantages, limitations, and clinical implications. It was thus necessary to conduct a comprehensive study including all three obesity indices.

Additionally, the association between parents-children could be modified by children's diet and physical activity [12,13]. However, only a few studies included these factors as covariates [14–17] and/or effect modifiers [9,18,19].

Therefore, the current study aimed to evaluate the potential two-year impact of parental obesity on children's obesity parameters in Chinese school-aged children. PBF, estimated by bioelectrical impedance analysis (BIA), was used as the primary outcome and BMI and WC were examined in secondary analyses. We also analyzed the interactions between parental obesity and potential effect modifiers, including children's sex, baseline age, and lifestyles.

Methods

Study population

The current study included all five primary schools in Gaohang Town, Shanghai, China. The initial sample was 3781 parent-children trios and 3699 were eligible after excluding 82 children and their parents (n = 77 born preterm and 5 aged ≥14). Of these, 58 refused to participate the study, leaving 3641 trios. The response rate was 98.4%. Further excluding participants with missing data (210 parents and 206 children) and participants who lost follow-up (1,159), 2066 trios remained in the current study (n = 1001 girls and 1065 boys, aged 6−14 years). The details of participant recruitment are shown in Fig. 1. Children's body weight, height, WC, and PBF were repeatedly measured in 2014 (baseline), 2015 and 2016, as described previously [21]. Parents signed informed consent forms. The study was approved by the Ethics Committee of Ren Ji Hospital, School of Medicine, Shanghai Jiao Tong University (AFINS-HOPE- 2013-06).

Anthropometrical data and body fat in children

Height (to the nearest 0.1 cm), weight (to the nearest 0.1 kg), and body fat (BIA method; TBF-410, Tokyo, Japan) were measured while children were barefoot and in underwear. Body fat was recorded as PBF (fat mass/body weight × 100) to the nearest 0.1%. BIA has been reported to be strongly associated with dual-energy X-ray absorptiometry [22] for estimation of PBF. Although BIA has not been validated in Chinese children, it is considered valid as an assessment of PBF based on a study conducted among Chinese adults [23]. BMI was calculated as the body weight (kg) divided by the height squared (m^2). Children's body weight was categorized into: 'normal' (<85th percentile), 'overweight' (95th percentile > BMI ≥ 85th percentile), or 'obese' (≥95th percentile) according to age- and sex-specific percentiles for Chinese children [24]. BMI z-score was calculated according to the Shanghai age- and sex-specific height and body weight 2007 standards [25]. WC was measured at the midpoint between the iliac crest and the lower rib (to the nearest 0.1 cm). These parameters were annually assessed by the same approaches and field workers during follow up. In the current study, we used PBF as the primary outcome, and the others as secondary outcomes.
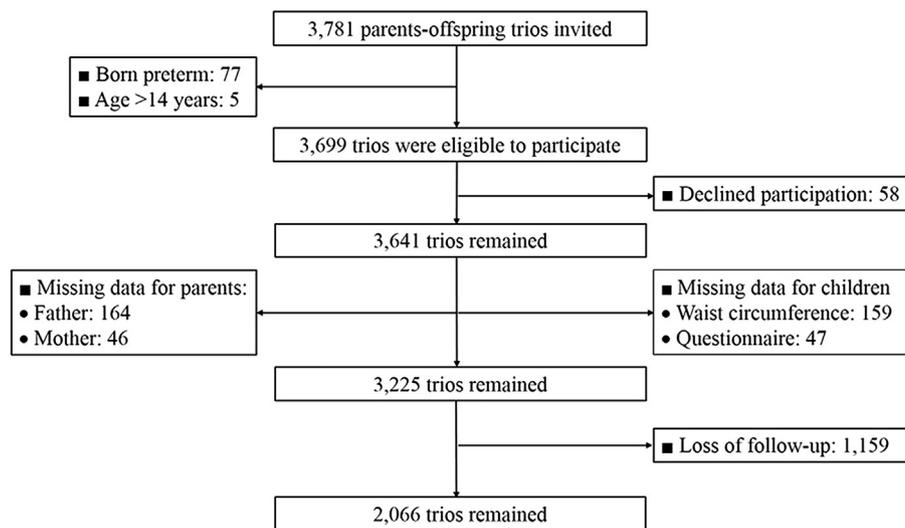

Figure 1 Eligible cohort and numbers included for analysis.

Parental obesity status

We collected information on self-reported parental height and body weight via a questionnaire at baseline. Parental BMI was calculated and categorized into three groups: 'normal' (BMI < 24.0 kg/m^2), 'overweight' (24 kg/m^2 ≤ BMI < 28.0 kg/m^2), or 'obese' (BMI ≥ 28.0 kg/m^2) according to the Working Group of Obesity in China (WGOC) criteria for adults [26].

Assessment of covariates

We collected information on children's age, sex, birthweight, physical activity, and diet by the same questionnaire. Information was recorded regarding the children's infant feeding pattern in their first four months, including breastfeeding (exclusive breastmilk except for water or syrups consisting of vitamins and mineral supplements), partial breast feeding (breastmilk with formula), and bottlefeeding (formula without breasting feeding). We collected dietary consumption of carbonated beverages (0–1, 2–3, 4–5, >5 bottles per week, one bottle = 500 ml), western fast food bought from restaurants (0–2, 3–4, 5–7, >8 times per month), traditional Chinese fried food (0–1, 2–3, 4–5 and >5 times per week), and processed meat (0–1, 2–4, 5–7, >8 times per week) in the last six months. The questionnaire was developed by the Centers for Disease Control and Prevention, China [27] and had been previously used in the same population to study the potential impact of diet on childhood obesity [28].

We created a diet quality score based on these four items, each of which has a minimum score of 1 (e.g., 0–1 bottle/wk of beverage) and a maximum score of 4 (e.g., >5 bottles/wk of beverage). The total score ranged from 4 points (best) to 16 points (worst). We found that diet quality score was associated with changes of PBF, BMI, and WC (r = 0.05, 0.07, and 0.07; all p < 0.01) after adjusting for sex and baseline age. We also collected parents' highest education level (≤elementary school, middle school, high school, ≥ college) and then classified education level into two groups: ≤middle school **or** ≥high school. Parents completed the questionnaire at the baseline.

Statistical analyses

Statistical analyses were performed using SAS version 9.4 (SAS Institute, Inc, Cary, NC). Formal hypothesis testing was two-sided with a significance level of 0.05. We used the PROC MIXED to evaluate the relationship between parental obesity (assessed by BMI and classified into 'normal', 'overweight', or 'obese') and children's obesity indices, which permits the examination of each time point, considering obesity indices at baseline and an interaction between obesity indices and time, where children's obesity indices were dependent variables while parental obesity were independent variables. Model 1 was a non-adjusted model. In model 2 we adjusted for parental education and for each of the parent's obesity status: maternal BMI was adjusted for among fathers, and paternal BMI was adjusted for among mothers.

We also explored whether children's age, sex, BMI z-score, diet quality score, and physical activity modified the potential association between parental obesity and children's obesity parameters. Subgroup analyses by these variables were further conducted.

Results

At the baseline, the children's mean age was 8.8 ± 1.9 years. Mean BMI, WC, and PBF for children was 17.6 ± 3.5 kg/m^2, 60.5 ± 9.6 cm, and 16.6 ± 6.5%, respectively. Mean BMI was 24.3 ± 3.0 kg/m^2 for fathers and 21.9 ± 2.9 kg/m^2 for mothers. The mean differences in BMI, WC, and PBF was 1.3 ± 1.4 kg/m^2, 3.9 ± 4.3 cm, and 0.7 ± 3.8%, respectively for boys during two-year follow-up, and 1.2 ± 1.4 kg/m^2, 4.7 ± 3.8 cm, and 2.5 ± 3.1% for girls. Boys tended to have a larger birthweight and WC, a higher prevalence of overweight and obesity, and a worse diet quality score, relative to girls (Table 1). The comparison of baseline characters across paternal and maternal obesity status is also shown in Supplemental Tables 1-2.

Maternal obesity was associated with a greater increase in children's PBF, BMI, and WC during the follow-up, after adjustment for parental education and paternal BMI (P-trend<0.01 for all; Table 2). Children with an obese mother had an additional increase of 0.41% [95% confidence interval (CI): 0.01%, 0.84%] for PBF, 0.29 kg/m^2 (95% CI: 0.13 kg/m^2, 0.45 kg/m^2) for BMI, and 0.76 cm (95% CI: 0.28 cm, 1.25 cm) for WC, compared with those children whose mothers were normal-weight (treated as the reference). There was a strong association observed for paternal obesity and a greater increase in children's BMI (0.13 kg/m^2; 95% CI: 0.03 kg/m^2, 0.24 kg/m^2) and WC (0.43 cm; 95% CI: 0.11 cm, 0.75 cm), but not PBF (Table 2).

The association between parental obesity and children's adiposity parameters was modified by children's sex, baseline age, BMI z-score, and diet quality score except for physical activity (Tables 3–4, Supplemental Table S3). In subgroup analyses, girls, younger children, and those with higher baseline BMI z-score and diet quality score were more likely to amass body fat when their parents were obese, relative to their counterparts. By contrast, the associations between paternal obesity and children's PBF only remained in younger children and children with a higher diet quality score (Table 3). The association is similar when considering parental obesity status and their children's BMI (Table 4) and WC (Supplemental Table S3). Overall, mothers had a more pronounced influence on their daughters' obesity parameters, while fathers influenced on their sons' obesity parameters.

Further adjusting for children's demographic factors, physical activity, and diet quality score did not materially change the association between parental obesity status and their children's obesity parameters (data not shown).

Discussions

In this two-year study including 2066 Chinese school-age children and their parents, we observed that both paternal

Table 1 Baseline characteristics of 2066 Chinese parents-children trios.

Variable	Group	Boys (1,065)	Girls (1,001)	P value
Age, %	6–9 y	66.0	69.1	0.11
	10–14 y	34.0	30.9	
Birth weight, %	Low	3.5	2.6	<0.001
	Normal	83.9	90.9	
	Macrosomia	12.6	6.5	
Infant feeding, %	Breast-feeding	51.6	50.3	0.63
	Partial breast-feeding	17.7	18.7	
	Bottle-feeding	30.7	31.0	
Obesity status, %	Normal	63.9	79.5	<0.001
	Overweight	18.5	11.7	
	Obese	17.6	8.8	
Children's BMI, kg/m^2 *	Year 2014	18.2 ± 3.7	16.9 ± 3.1	<0.001
	Year 2015	19.0 ± 3.8	17.7 ± 3.2	<0.001
	Year 2016	19.2 ± 4.0	17.8 ± 3.3	<0.001
Children's waist circumference, cm*	Year 2014	63.1 ± 10.2	57.8 ± 8.1	<0.001
	Year 2015	65.8 ± 10.6	61.4 ± 8.6	<0.001
	Year 2016	66.6 ± 10.5	61.5 ± 8.3	<0.001
Children's percentage of body fat, *	Year 2014	16.7 ± 6.4	16.6 ± 6.6	0.35
	Year 2015	17.4 ± 6.8	18.0 ± 6.8	0.05
	Year 2016	17.4 ± 6.7	18.3 ± 6.9	0.004
Diet quality score, points*	–	5.2 ± 1.5	4.8 ± 1.2	<0.001
Physical activity, %	<1 h/d	34.4	31.2	0.11
	≥1 h/d	65.6	68.8	
Paternal obesity status, %	Normal	46.8	50.3	0.07
	Overweight	42.4	40.5	
	Obese	10.8	9.2	
Paternal education, %	≤Middle school	58.5	55.0	0.09
	≥High school	41.5	45.0	
Maternal obesity status, %	Normal	80.1	80.2	0.91
	Overweight	15.9	16.2	
	Obese	4.0	3.6	
Maternal education, %	≤Middle school	62.7	59.3	0.1
	≥High school	37.3	40.7	

1. *, continuous variables, shown as mean ± standard deviation.
2. Diet quality score was based on the consumption of carbonated beverage, western fast food, traditional Chinese fried food, and processed meat, each of these 4 items has a minimum score of 1 and a maximum score of 4. The total score ranged from 4 points (best) to 16 points (worst).
3. Children's obesity status was defined as following: 'normal' (BMI<85th percentile), 'overweight' (95th percentile > BMI≥85th percentile), **or** 'obese' (≥95th percentile), according to age and sex specific percentile for Chinese children.
4. Parental obesity status was defined as following: 'normal' (BMI < 24.0 kg/m^2), 'overweight' (24 kg/m^2 ≤ BMI < 28.0 kg/m^2), **or** 'obese' (BMI ≥ 28.0 kg/m^2) according to the Working Group of Obesity in China (WGOC) criteria for adults.

Table 2 Mean difference and 95% confidence interval in annual increasing rate of PBF (%), BMI (kg/m^2), and WC (cm), according to baseline maternal and paternal obesity groups in 2066 Chinese parents-children trios.

Exposure		Maternal obesity groups			P trend	Paternal obesity groups			P trend
		Normal (n = 1673)	Overweight (n = 321)	Obese (n = 72)		Normal (n = 997)	Overweight (n = 857)	Obese (n = 212)	
PBF	Model 1	**0 (ref)**	0.38 (0.16, 0.61)	0.42 (0.01, 0.85)	<0.001	**0 (ref)**	−0.07 (−0.35, 0.22)	0.13 (−0.04, 0.31)	0.21
	Model 2	**0 (ref)**	0.38 (0.16, 0.61)	0.41 (0.01, 0.84)	0.001	**0 (ref)**	−0.07 (−0.35, 0.22)	0.13 (−0.04, 0.3)	0.22
BMI	Model 1	**0 (ref)**	0.2 (0.13, 0.29)	0.29 (0.13, 0.45)	<0.001	**0 (ref)**	0.1 (0.03, 0.16)	0.13 (0.03, 0.24)	0.003
	Model 2	**0 (ref)**	0.21 (0.12, 029)	0.29 (0.13, 0.45)	<0.001	**0 (ref)**	0.1 (0.04, 0.17)	0.13 (0.03, 0.24)	0.003
WC	Model 1	**0 (ref)**	0.57 (0.32, 0.83)	0.77 (0.28, 1.25)	<0.001	**0 (ref)**	0.29 (0.09, 0.49)	0.43 (0.11, 0.75)	0.003
	Model 2	**0 (ref)**	0.57 (0.32, 0.83)	0.76 (0.28, 1.25)	<0.001	**0 (ref)**	0.29 (0.09, 0.49)	0.43 (0.11, 0.75)	0.003

1. **BMI**, body mass index; **PBF**, percentage of body fat; **WC**, waist circumference.
2. **Model 1**: non-adjusted model.
3. **Model 2**: Adjusted for paternal education (≤middle school or ≥ high school), and maternal education (≤middle school or ≥ high school), for each of the parent's obesity status: maternal BMI was adjusted for among fathers, and paternal BMI was adjusted for among mothers.
4. Maternal and paternal obesity was defined as following: 'normal' (BMI < 24.0 kg/m^2), 'overweight' (24 kg/m^2 ≤ BMI < 28.0 kg/m^2), or 'obese' (BMI ≥ 28.0 kg/m^2) according to the Working Group of Obesity in China (WGOC) criteria for adults.
5. Bold signifies children whose parents with normal body weight was treated as "ref". The change for reference group is considered as "0".

Table 3 Mean difference and 95% confidence interval in annual increasing rate of PBF (%) according to baseline maternal and paternal obesity groups, stratified by children's sex, baseline age, BMI z-score, diet quality score, and physical activity.

Stratified variables	Groups	Maternal obesity groups			P trend	P interaction	Paternal obesity groups			P trend	P interaction
		Normal (n = 1673)	Overweight (n = 321)	Obese (n = 72)			Normal (n = 997)	Overweight (n = 857)	Obese (n = 212)		
Sex	Boys	**0 (ref)**	0.23 (−0.4, 0.85)	0.31 (−0.03, 0.64)	0.18	<0.001	**0 (ref)**	−0.13 (−0.54, 0.28)	0.16 (−0.1, 0.42)	0.27	<0.001
	Girls	**0 (ref)**	0.43 (0.16, 0.7)	0.55 (0.01, 1.08)	0.002		**0 (ref)**	0.13 (−0.23, 0.48)	0.19 (−0.02, 0.41)	0.21	
Age	<10 y	**0 (ref)**	0.39 (0.02, 0.8)	0.42 (0.2, 0.64)	<0.001	<0.001	**0 (ref)**	0.05 (−0.23, 0.33)	0.22 (0.06, 0.39)	0.03	0.01
	≥10 y	**0 (ref)**	0.22 (−0.99, 1.43)	0.44 (−0.16, 1.04)	0.35		**0 (ref)**	−0.36 (−1.1, 0.39)	−0.28 (−0.79, 0.23)	0.45	
BMI z-score	<0.34	**0 (ref)**	0.4 (0.1, 0.7)	0.57 (0.01, 1.14)	0.007	<0.001	**0 (ref)**	−0.19 (−0.61, 0.22)	0.07 (−0.13, 0.28)	0.43	0.001
	≥0.34	**0 (ref)**	0.37 (−0.25, 0.99)	0.41 (0.07, 0.79)	0.041		**0 (ref)**	0.07 (−0.34, 0.48)	0.2 (−0.09, 0.49)	0.38	
Diet quality score	<5	**0 (ref)**	−0.06 (−0.73, 0.6)	0.12 (−0.18, 0.42)	<0.001	<0.001	**0 (ref)**	−0.04 (−0.27, 0.19)	0.18 (−0.21, 0.56)	0.56	0.03
	≥5	**0 (ref)**	1.29 (0.16, 2.41)	1.69 (0.21, 3.59)	0.72		**0 (ref)**	−0.27 (−0.68, 0.14)	0.3 (0.03, 0.56)	0.02	
Physical activity	<1 h/d	**0 (ref)**	0.48 (−0.2, 1.16)	0.73 (0.58, 0.81)	<0.001	0.007	**0 (ref)**	0.15 (−0.32, 0.62)	0.21 (−0.06, 0.49)	0.31	0.46
	≥1 h/d	**0 (ref)**	0.21 (−0.07, 0.5)	0.38 (−0.16, 0.92)	0.16		**0 (ref)**	−0.17 (−0.52, 0.18)	0.08 (−0.15, 0.3)	0.4	

1. **BMI**, body mass index; **h**, hour.
2. BMI z-score was stratified by medium (0.34; −0.55, 1.28). Diet quality score was stratified by medium (5.0; 4.0, 13.0).
3. Adjusted for paternal education (≤middle school or ≥ high school), and maternal education (≤middle school or ≥ high school), for each of the parent's obesity status: maternal BMI was adjusted for among fathers, and paternal BMI was adjusted for among mothers.
4. Maternal and paternal obesity was defined as following: 'normal' (BMI < 24.0 kg/m^2), 'overweight' (24 kg/m^2 ≤ BMI < 28.0 kg/m^2), or 'obese' (BMI ≥ 28.0 kg/m^2) according to the Working Group of Obesity in China (WGOC) criteria for adults.
5. Bold signifies children whose parents with normal body weight was treated as "ref". The change for reference group is considered as "0".

Table 4 Mean difference and 95% confidence interval in annual increasing rate of BMI (kg/m^2) according to baseline maternal and paternal obesity groups, stratified by children's sex, baseline age, BMI z-score, diet quality score, and physical activities.

Stratified variables	Groups	Maternal obesity groups			P trend	P interaction	Paternal obesity groups			P trend	P interaction
		Normal (n = 1673)	Overweight (n = 321)	Obese (n = 72)			Normal (n = 997)	Overweight (n = 857)	Obese (n = 212)		
Sex	Boys	**0 (ref)**	0.17 (−0.05, 0.39)	0.23 (0.11, 0.35)	<0.001	<0.001	**0 (ref)**	0.13 (0.04, 0.22)	0.16 (0.02, 0.31)	0.008	0.005
	Girls	**0 (ref)**	0.19 (0.08, 0.31)	0.35 (0.12, 0.58)	<0.001		**0 (ref)**	0.06 (−0.03, 0.16)	0.1 (−0.06, 0.25)	0.29	
Age	<10 y	**0 (ref)**	0.25 (0.16, 0.33)	0.42 (0.26, 0.59)	<0.001	<0.001	**0 (ref)**	0.13 (0.07, 0.2)	0.26 (0.15, 0.37)	<0.001	<0.001
	≥10 y	**0 (ref)**	−0.1 (−0.53, 0.33)	0.11 (−0.1, 0.33)	0.49		**0 (ref)**	−0.02 (−0.2, 0.16)	−0.15 (−0.41, 0.11)	0.53	
BMI z-score	<0.34	**0 (ref)**	0.14 (−0.06, 0.34)	0.17 (0.07, 0.28)	0.003	<0.001	**0 (ref)**	0.07 (−0.04, 0.19)	0.12 (−0.04, 0.27)	0.27	<0.001
	≥0.34	**0 (ref)**	0.19 (0.06, 0.32)	0.33 (0.09, 0.57)	<0.001		**0 (ref)**	0.04 (−0.1, 0.18)	0.09 (0.02, 0.16)	0.04	
Diet quality score	<5	**0 (ref)**	0.15 (−0.1, 0.4)	0.16 (0.05, 0.27)	0.01	<0.001	**0 (ref)**	0.03 (−0.12, 0.18)	0.15 (0.05, 0.25)	0.009	<0.001
	≥5	**0 (ref)**	0.26 (0.13, 0.38)	0.37 (0.16, 0.58)	<0.001		**0 (ref)**	0.06 (−0.04, 0.14)	0.25 (0.1, 0.39)	0.004	
Physical activity	<1 h/d	**0 (ref)**	0.17 (0.07, 0.28)	0.31 (0.11, 0.51)	<0.001	<0.001	**0 (ref)**	0.1 (0.01, 0.18)	0.14 (0.02, 0.27)	0.02	0.03
	≥1 h/d	**0 (ref)**	0.24 (−0.03, 0.51)	0.27 (0.13, 0.41)	<0.001		**0 (ref)**	0.1 (−0.01, 0.2)	0.1 (−0.08, 0.28)	0.18	

1. **BMI**, body mass index; **h**, hour.
2. BMI z-score was stratified by medium (0.34; −0.55, 1.28). Diet quality score was stratified by medium (5.0; 4.0, 13.0).
3. Adjusted for paternal education (≤middle school or ≥ high school), and maternal education (≤middle school or ≥ high school), for each of the parent's obesity status: maternal BMI was adjusted for among fathers, and paternal BMI was adjusted for among mothers.
4. Maternal and paternal obesity was defined as following: 'normal' (BMI < 24.0 kg/m^2), 'overweight' (24 kg/m^2 ≤ BMI < 28.0 kg/m^2), or 'obese' (BMI ≥ 28.0 kg/m^2) according to the Working Group of Obesity in China (WGOC) criteria for adults.
5. Bold signifies children whose parents with normal body weight was treated as "ref". The change for reference group is considered as "0".

and maternal obesity was associated with certain children's obesity indices. Overall, mothers appeared to have a greater influence than fathers, though the associations varied across outcomes.

Both parents influence their children's dietary intake and physical activity [29,30]. However, a man's behaviors and environmental exposures could also shape his children's development and future health even before sperm meets egg [31]. Although both maternal and paternal obesity were associated with children's BMI/WC, the association seem to be stronger in mother−children pairs than in father−children pairs, as suggested by the current study. We also found that having an overweight mother, but a normal weight father was associated with a greater increase of BMI and WC, but not for the reverse scenario (an overweight father with a normal weight mother). The results were consistent with previous studies performed in the US [4,8,32] and Germany [5]. The possible mechanism remains uncertain and both genetic and environmental factors are possibly involved [33]. However, these notions were not supported by another cross-sectional study (n = 12,181) of Belarusian children published in 2011 [6] and a cohort study (n = 4654) of British children published in 2010 [7], which did not find a stronger association of maternal obesity than paternal obesity with their children's BMI. Further studies are needed.

We observed a strong association between maternal obesity and children's PBF, but not paternal obesity. The results were consistent with a cross-sectional study including 4091 British parent-children trios in 2008 [32] and another 2010 study of English children (n = 4432 families, n = 7078 children) [4]. The smaller paternal effects could partially due to undisclosed non-biological fathers in some of the families. However, a low nonpaternity rate ($\leq$4%) could only explain a small proportion of the maternal-paternal differences [4]. One possible explanation is that because the ovum is substantially larger than the sperm, it contributes both more genetic and epigenetic material to the offspring [33]. Further, the maternal uterine environment is also associated with offspring's adiposity [34]. Another possible explanation is that mothers are generally more likely to be the primary caregiver for children than fathers, who may have less influence on the food provided to the children, and no influence or smaller influence on children's PBF [35]. By contrast, a 2011 cross-sectional study of Belarusian children observed similar positive dose-response associations of a mother's and father's BMI with their children's adiposity (BMI, WC and skinfolds) [6]. The disparity could be due to the study population being relatively lean and healthy − only 2% of children were obese [6]. In the current study, the prevalence of obesity for the children was 13.4% in children.

Several factors could modify the observed associations between parents and children. A 2010 study of British children found that the associations between parental obesity and children's BMI changed when parental socioeconomical conditions were improved [18]. Another

2011 study of Swedish children also found that parental BMI was associated with severity of obesity in children and the association was strengthened when children grew into adolescence (age 15) [19]. Younger children are more likely to receive influences on their diet and exercising from their parents. In contrast, older children are more subjected to stronger peer influence and acquire greater autonomy when making food choices [36]. The critical window for transmission of energy-saving efficiency (i.e., the capability to store excess energy in the body owing to an energy imbalance between intake and expenditure) from obese parents to their children is limited to childhood and these parental influences could disappear in adolescent and adult children [37]. We also observed that lifestyle factors, such as diet and physical activity, modified the association between parental obesity and children's obesity indices. The association of obesity between parents and children was stronger in children with a less healthy diet and less physical activity. These factors have been shown to interact with genetic factors in relation to obesity [12,13]. However, the interactions between physical activity and parents' obesity status, in relation to children's obesity, have been investigated only in a few studies. A 2001 study of British children and their families found that children from overweight/obese families had a stronger preference for sedentary activity and spent more time in sedentary pastimes, relative to those from normal weight families [17]. Together with this study, our results highlight the importance of adherence to a healthier lifestyle for those children with obese parents.

Strengths of the current study included its cohort study design, relatively precise method for body fat estimation, and large sample size. Our study also has several limitations. First, dietary intake (e.g., the consumption of carbonated beverages), driving factors for overweight and obesity in Chinese children [38,39], was assessed by a parents-completed questionnaire, which was not validated previously and was subject to information bias. However, we found that diet quality score was associated with the changes in PBF, BMI, and WC during the follow-up. Second, we used self-reported parental height and body weight, which may introduce misclassification. Of note, self-reported weight was commonly used in previous studies [40] and has been shown to be highly correlated with measured weight [41]. Residual confounding is also of concern. For example, parents' diet quality was not available, which could have impact on both exposure and outcome in the current study. We did not collect data on sexual maturation and body size changed rapidly during puberty [15]. We thus conducted a subgroup analyses, stratified by age, and found a stronger association among younger participants (aged <10 y). Similarly, we did not collect the information on biological relationship between parents and children. However, it is considered that as the divorce rate is low in China (3.2%, based on a 2017 government report), the study parents and children were most likely to be biologically related.

Conclusions

Both paternal and maternal obesity were associated with children's obesity indices. The association was stronger in mother−children pairs than in father−children pairs. Improvements in children's lifestyles, such as increased physical activity and adherence to a healthier diet, could reduce their PBF, BMI and WC.

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Conflicts of interest

The authors declared nothing to be reported.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.numecd.2018.11.004.

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